(19) **European Patent Office**

(11) Publication number: **0 031 278**
A1

(12) **EUROPEAN PATENT APPLICATION**

(21) Filing number: **80401777.0**

(22) Filing date: **11 December 1980**

(51) Int. cl.^{3}: **G 02 B 5/28**
G 02 B 5/22, G 02 C 7/10

(30) Priority: **19 December 1979 FR 7931037**

(43) Publication date of the application:
1 July 1981 Bulletin 81/26

(84) Named contracting nations:
DE GB SE

(71) Applicant: **FRENCH NATION represented by the GENERAL DELEGATE FOR ARMAMENTS**
Office of Patents and Inventions of the General Delegation for Armaments
14, rue Saint-Dominique
F-75997 Paris Armées (FR)

(72) Inventor: **Farges, Guy**
7, Boulevard de Stalingrad
F-92320 Chatillon (FR)

(54) **Optical interference filter for protection against infrared radiation and application.**

(57) The invention relates to an optical interference filter for protection against infrared radiation whose pass-band is situated in the visible and centered on the sensitivity maximum of the eye.

This filter comprises a substrate which is at least partially transparent in the visible band, on one of whose faces is deposited the filter itself composed of n filtering elements, each comprising a layer of metal, silver for example, interposed between two layers of a transparent dielectric material with a high refractive index, zinc sulfide for example, n being a whole number greater than or equal to 3. The thickness of the metal layers is on the order of 20 nm and that of the dielectric layers is on the order of 30 to 45 nm.

This filter is suitable for the construction of devices for protection of the eye, for example against the radiation emitted by neodymium lasers.

OPTICAL INTERFERENCE FILTER FOR PROTECTION AGAINST INFRARED RADIATION AND APPLICATION.

The technical field of this invention is that of optical filters used to strongly attenuate the infrared radiation of the electromagnetic spectrum while transmitting the visible radiation.

It is well known that the phenomenon of vision is made possible solely by the radiation of the visible spectrum, i.e., the electromagnetic radiation having wavelengths of between 400 and 700 nm. This radiation presents no danger to the eye if its intensity is not too great, in contrast to that of the ultraviolet and infrared ranges, which can cause serious injuries even at relatively low doses. More particularly, when one wishes to protect oneself against the emission of a neodymium laser, the ideal protection filter would exhibit a maximum transmission factor over the entire extent of the visible range and would considerably attenuate the radiation at λ = 1060 nm. The attenuation can be achieved either by absorption or by reflection of the harmful radiation. Hence, we are going to be interested more specifically in eliminating the radiation at 1060 nm, without this being considered as a limitation of the applications of this invention.

Protection of the eyes against the emission of a neodymium laser is most often accomplished by using mineral or organic glasses tinted throughout. An example of a mineral glass used for infrared protection is the glass of type KG 3 manufactured by the German company SCHOTT. With a thickness of 2 mm this glass has an optical density on the order of 3 for λ = 1060 nm and a mean transmission factor in the visible of about 70%. A higher optical density in the infrared is obtained by increasing the thickness of the glass. It should be noted that this filter attenuates the entire infrared spectrum.

An example of an organic glass has been proposed by the American company GLENDALE OPTICAL CORPORATION INC. It makes it

possible to obtain a very high optical density (~ 30) for λ = 1060 nm. However, the maximum transmission factor in the visible is only on the order of 20% and the width of the pass-band is about 60 nm. Hence, vision through this filter is weakened and also the perception of colors is extremely distorted.

Besides these devices, other solutions have been proposed to attenuate infrared radiation, notably the use of glass or plastic substrates covered with one or more thin layers of metal, particularly gold or copper.

For example, American patent 3,118,781 proposes a filter comprising a substrate of, for example, Mylar covered by a layer of gold protected by an external layer of resin. This type of filter, although providing satisfaction for certain uses such as the protection of welders, is not suitable for laser protection at λ = 1060 nm. In fact, the optical density for that wavelength is very inadequate and the visible range is considerably attenuated. Moreover, the internal surface of this type of filter is very reflective, so that the eye receives the major part of the light arriving through the back, resulting in an intolerable visual discomfort.

The solution which consists of using complex filters composed of a substrate covered with several thin layers, such as that proposed in French patent 2,003,277, has the advantage of having an internal surface that does not reflect visible light. However, they have the drawback of filters with metal layers of attenuating the visible range in an exaggerated manner without ensuring a true elimination of the radiation at λ = 1060 nm.

In French patent 2,276,601 there was proposed a band filter designed to protect the vision against the flash of light and heat from a nuclear explosion. This filter is composed of a substrate covered with a set of alternating metal and dielectric layers. While this filter strongly attenuates transmission in the ultraviolet and infrared ranges while ensuring a faithful perception of colors, it has the drawback of notably attenuating the visible range. By way of example, a filter having an optical

density on the order of 4.5 for λ = 1060 nm has a transmission factor on the order of 10% for λ = 550 nm.

Stacks consisting of dielectric materials with alternating high and low indices of refraction offer the possibility of obtaining a very high transmission factor in the visible while attenuating the wavelength of 1060 nm. However, obtaining a high optical density at this wavelength requires a large number of layers on the order of twenty.

In French patent 2,106,431 there was proposed an interference filter designed to transmit visible light and to reflect the infrared range. This filter is composed, for example, of a substrate on which are deposited, in order, a layer of alumina-based dielectric, a layer of metal, a layer of zinc-sulfide-based dielectric, a layer of metal and finally a dielectric layer. In the journal "APPLIED OPTICS", vol. 15, no. 4, April 1976, there was described a filter usable against the transmission of infrared and ultraviolet radiation, comprising a substrate, a layer of titanium dioxide, a layer of metal (silver) and a layer of titanium dioxide. The mean transmission in the visible is on the order of 70 to 80%, but the optical density for λ = 1060 nm is only on the order of one. It is out of the question to use such filters for protection against the emission of a neodymium laser.

In American patent (reissued) 27,473 there was proposed a filter for making eyeglass lenses that filter the infrared and ultraviolet, composed of a transparent glass substrate on which are deposited a layer of a dielectric (titanium dioxide, for example), a layer of metal (silver or gold, for example) and finally a layer of an antireflective element. However, the transmission is very low in the vicinity of 510 nm.

The present invention has as its aim to provide an optical filter designed to ensure protection of the eyes against infrared radiation while interfering as little as possible with the vision, notably with the perception of colors. It has the further aim of ensuring this protection even in the presence of intense luminous flux at the wavelength of λ = 1060 nm.

The invention thus has as its object an optical interference filter for protection against infrared radiation whose pass-band is situated in the visible and centered on the sensitivity maximum of the eye, comprising a substrate which is at least partially transparent in said band, on one of whose faces is deposited an optical filter, characterized in that the filter is composed of n filtering elements each comprising a layer of metal interposed between two layers of a transparent dielectric material with a high index of refraction, n being a whole number greater than or equal to 3.

The thickness of the metal layers is greater than or equal to 20 nm, and the thickness of the layers of dielectric material is between approximately 30 and 45 nm.

Advantageously the metal layers are chosen from the group: aluminum, copper, rhodium, platinum, gold, silver and the dielectric material from the group of the oxides of: bismuth, lead, tin, indium, aluminum, silicon, rare earths; dioxides of: titanium, zirconium; pentoxides of: niobium, tantalum; and zinc sulfide.

The metal layer is made of silver and the layer of dielectric material is made of zinc sulfide.

Preferentially, in an embodiment designed to protect against the radiation emitted by neodymium lasers with an optical density on the order of 4 for λ = 1060 nm, n is equal to 4, the thickness of the intermediate layer of dielectric made of zinc sulfide is on the order of 70 nm, and the thickness of the end layers of dielectric is on the order of 40 nm.

In another embodiment designed to protect against the radiation emitted by neodymium lasers with an optical density on the order of 5.5 for λ =1060 nm, n is equal to 5, the thickness of the intermediate layer of dielectric made of zinc sulfide is on the order of 40 nm.

The optical filter according to the invention is suitable for the construction of devices for protection of the human eye.

A first result provided by the filter according to the

invention lies in the fact that the optical density obtained is high in the range of infrared radiation, while providing a transmission factor on the order of 10% in the visible range.

Another result lies in the fact that the pass-band of the filter according to the invention is centered on the sensitivity maximum of the eye (λ = 550 nm) and its bandwidth is on the order of 220 nm, which interferes little with the perception of colors.

Another result of the filter according to the invention is that it can be implemented on any type of optical substrate, and particularly on convex substrates of large area. It offers the advantage of withstanding the adhesive-tape test and passing the climatic and environmental tests applicable to this type of material.

The optical properties of the filter according to the invention are homogeneous and vary little as a function of the angle of incidence of a laser beam.

The protection filter which is the object of the invention thus comprises a transparent or semi-transparent substrate on one of whose faces are deposited the filtering elements. All the substrates ordinarily used in this technical field can be used; it suffices that they transmit visible energy well. By way of example, one can use a mineral glass or a plastic material. The thickness of this substrate is not critical, but it is necessary that it ensure the mechanical rigidity of the entirety.

The metal layers can be made of one or more of the metals usually used in interference optics, such as aluminum, copper, rhodium and platinum, but gold or better still silver will be used advantageously. The dielectric layers are also composed of one or more of the materials generally used in interference optics, such as bismuth oxide, lead oxide, tin oxide, indium oxide, titanium dioxide, zirconium dioxide, niobium pentoxide, tantalum pentoxide, aluminum oxide, silicon oxides, zinc sulfide, rare-earth oxides. However, to optimize the value of the maximum transmission factor in the visible and the width of the pass-band, materials with a high refractive index will be used advan-

tageously, i.e., titanium dioxide and zinc sulfide. In fact, for a given metal, preferably gold or silver, it has been found that the contrast factor of the optical element is higher the higher the refractive index of the transparent material itself.

It is known that the thickness of the dielectric layers determines the position of the pass-band in the visible spectrum. However, it has been discovered that there exists, in first approximation, an optimal ratio between the thicknesses of the metal and dielectric layers. According to the invention, the optical thicknesses of the dielectric layers are chosen so as to obtain an antireflective treatment at the maximum for the metal layers in the visible. One thus obtains a maximum transmission factor in that range. But, on the other hand, the thicker will be the metal layers and the higher will be the optical density at λ = 1060 nm and generally in the infrared. From this compromise results the invention, which uses metal layers whose thickness is at least equal to 20 nm.

To construct a filter according to the invention, one can proceed in the following manner. One uses, for example, the techniques of vacuum evaporation or cathode sputtering or equivalent techniques to deposit the successive layers of metal and dielectric. The substrate is disposed on a rotating unit and the evaporation sources of the metals and dielectrics are placed near this unit. The thickness of the various layers is monitored in a known manner by recording the filter's transmission factor during its fabrication.

The invention will be best understood from specific embodiments, given indicatively without any restrictive nature, together with the drawings in which:

- Figure 1 represents a transverse section of an embodiment in which n = 4,
- Figure 2 also represents a transverse section of an embodiment in which n = 5,
- Figure 3 represents the variation of the optical density of a certain number of filters of the prior art as a function of

wavelength,

- Figure 4 represents the variation of the optical density of two filters according to the invention as a function of wavelength.

The filters according to the invention are prepared by the technique of vacuum evaporation in a BALZERS Model BAK 550 evaporator manufactured by the BALZERS Company. The substrates to be treated, [which are] sheets of transparent mineral glass with a refractive index n = 1.52 or disks of plastic material such as polycarbonate, are disposed on a rotating dome situated 600 mm from its base. The evaporation sources, situated on a circular arc of diameter 400 mm and at a height of 150 mm from the base of the evaporator, are two boats, one made of tungsten and the other of molybdenum. The tungsten boat contains gold or silver; the molybdenum boat contains zinc sulfide. A device for measuring the thickness of the layers makes it possible to monitor the filter's transmission factor continuously during its fabrication.

After a vacuum has been created in the evaporator down to a pressure of a few 10^{-2} Torr, a luminescent discharge is produced for 10 nanominutes, intended to complete the cleaning of the substrates by ion bombardment. Then the pumping is continued until a pressure of 1×10^{-6} Torr is obtained. Then the various layers of materials are deposited, without interrupting the vacuum, by heating the boats alternatingly and successively to the evaporation temperature of silver or the sublimation temperature of zinc sulfide. When the desired thickness for each layer is reached, a screen interposed between the evaporation sources and the substrates quickly interrupts the deposition.

EXAMPLE 1

The filter shown schematically in Figure 1 is produced as indicated above. On the substrate 1 made of glass with a refractive index n = 1.52, layers of zinc sulfide 2, 4, 6, 8, 10 and layers of silver 3, 5, 7, 9 are deposited alternatingly with the

following thicknesses:

Layer number	Index of the material or material	Thickness in nm
10	2.3	40
9	Ag	20
8	2.3	73
7	Ag	23
6	2.3	70
5	Ag	23
4	2.3	73
3	Ag	20
2	2.3	42

In Figure 1, curve 1 represents the optical density of a filter according to French patent 2,106,431, curve 2 represents the optical density of an organic glass used in the prior art and curve 3 represents that of a filter according to French patent 2,276,601.

In Figure 4, curve 4 represents the optical density of the filter prepared previously, and it can be seen that near $\lambda = 1060$ nm it has a density on the order of 4, a value which is clearly greater than the values obtained previously according to curves 1 and 2 and practically of the same order of magnitude as that obtained according to curve 3.

<u>EXAMPLE 2</u>

The filter shown schematically in Figure 2 is produced in the same way by depositing on the substrate 11 the layers of zinc sulfide 12, 14, 16, 18, 20, 22 and the layers of silver 13, 15, 17, 19, 21 with the following thicknesses:

Layer number	Index of the material or material	Thickness in nm
22	2.3	40
21	Ag	20
20	2.3	73
19	Ag	23
18	2.3	70
17	Ag	24
16	2.3	70
15	Ag	23
14	2.3	73
13	Ag	20
12	2.3	42

Curve 5 in Figure 4 represents the variation of the optical density of such a filter. It can be seen that near $\lambda = 1060$ nm this filter has an optical density greater than 5.5. A filter of this type is particularly well suited for protection against the emission of a neodymium laser.

In comparison with the embodiment in Figure 1, this filter has one additional metal layer and one additional dielectric layer. These two layers have the effect of increasing by one the value of the optical density at $\lambda = 1060$ nm without appreciably changing the transmission in the visible range, which remains very high.

Various modifications within reach of a person skilled in the art can be made to the filter according to the invention. Thus, with the aim of enhancing the transmission in the visible it is possible to interpose a layer of a material having a low refractive index, preferably between the substrate and the first dielectric layer.

CLAIMS

1 - Optical interference filter for protection against infrared radiation, whose pass-band is situated in the visible and centered on the sensitivity maximum of the eye, comprising a substrate which is at least partially transparent in said band, on one of whose faces is deposited an optical filter, characterized in that the filter is composed of n filtering elements, each comprising a layer of metal interposed between two layers of a transparent dielectric material with a high refractive index, n being a whole number greater than or equal to 3.

2 - Optical filter according to claim 1, characterized in that the thickness of the metal layers is greater than or equal to 20 nm, and the thickness of the layers of dielectric material is between approximately 30 and 45 nm.

3 - Optical filter according to claim 1 or 2, characterized in that the metal layers are chosen from the group: aluminum, copper, rhodium, platinum, gold, silver and the dielectric material from the group of the oxides of: bismuth, lead, tin, indium, aluminum, silicon, rare earths; dioxides of: titanium, zirconium; pentoxides of: niobium, tantalum; and zinc sulfide.

4 - Optical filter according to claim 3, characterized in that the metal layer is made of silver and the layer of dielectric material is made of zinc sulfide.

5 - Optical filter according to claim 4 designed for protection against the radiation emitted by neodymium lasers, characterized in that n = 4, the thickness of the intermediate layers of zinc sulfide being on the order of 70 nm, and the thickness of the end layers of dielectric being on the order

of 40 nm.

6 - Optical filter according to claim 5 designed for protection against the radiation emitted by neodymium lasers, characterized in that n = 5, the thickness of the intermediate layers of zinc sulfide being on the order of 70 nm, and the thickness of the end layers of dielectric being on the order of 40 nm.

7 - Application of the filters according to any of claims 1 to 4 for the construction of devices for protection of the human eye.

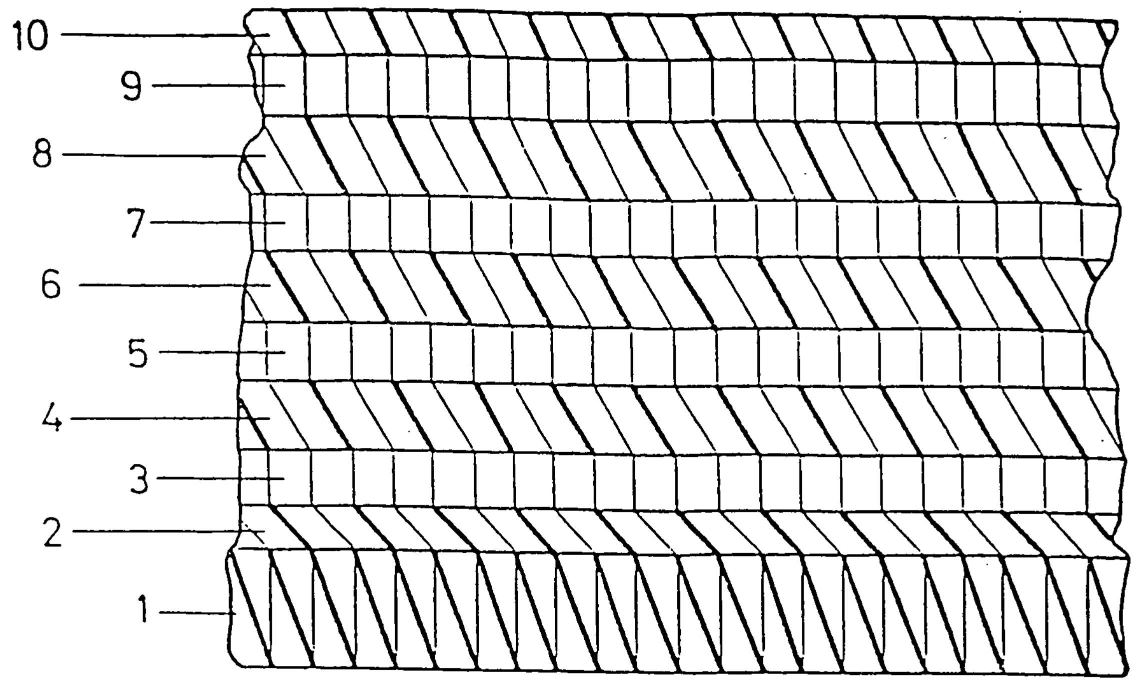


FIG. 1

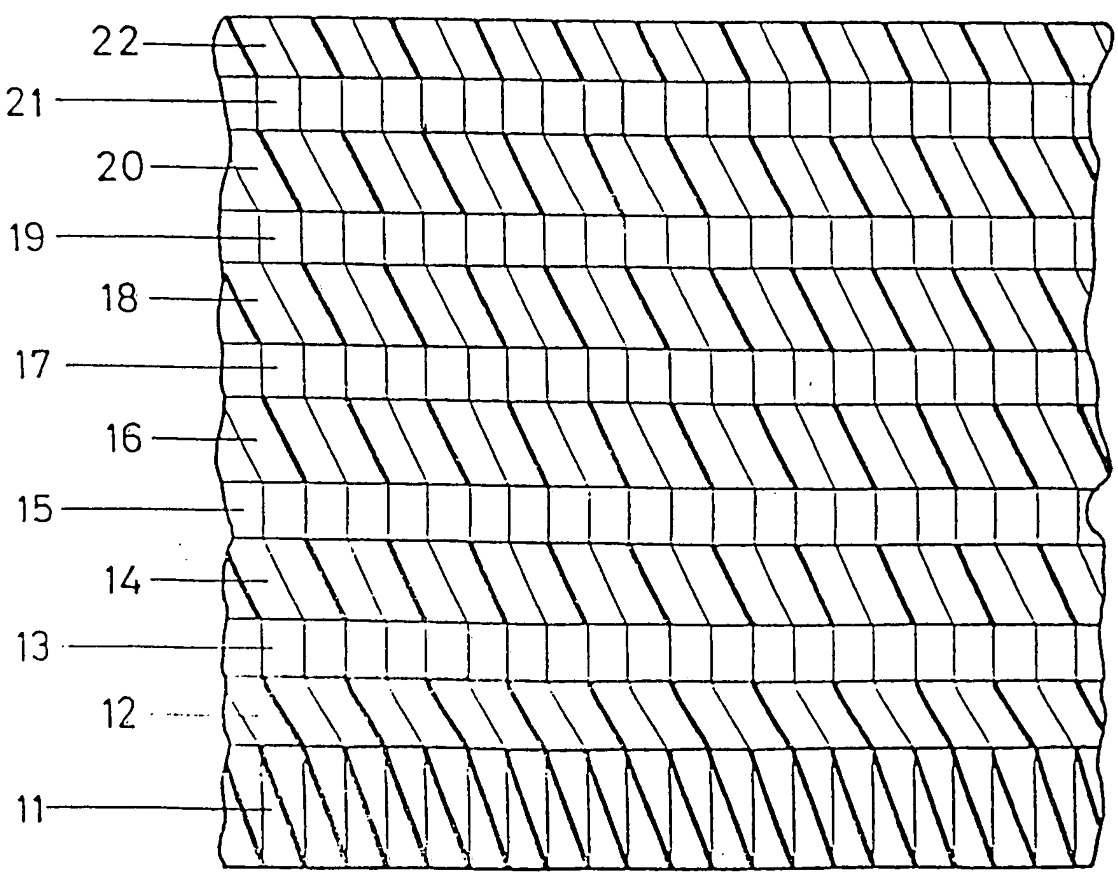


FIG. 2

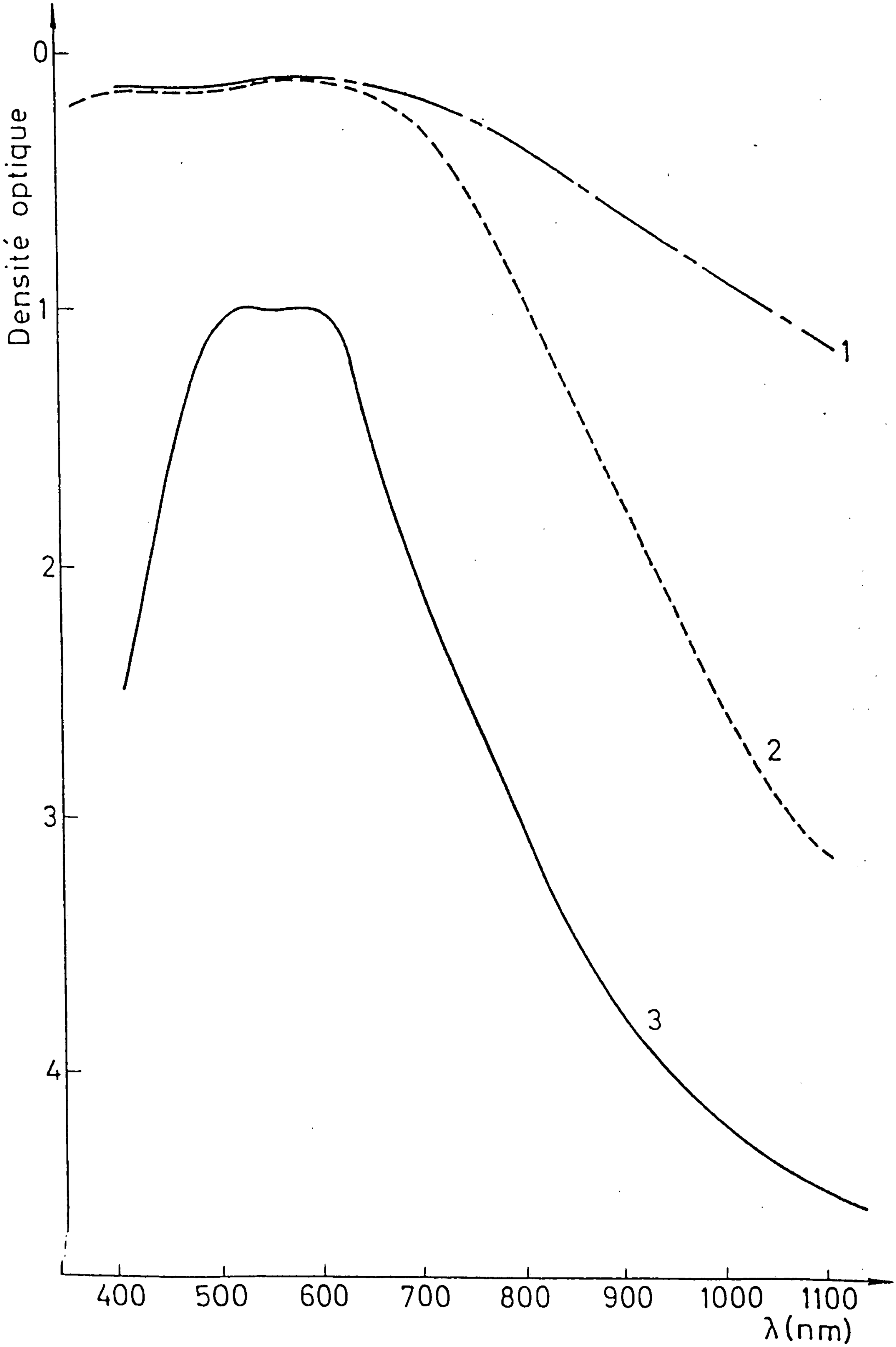
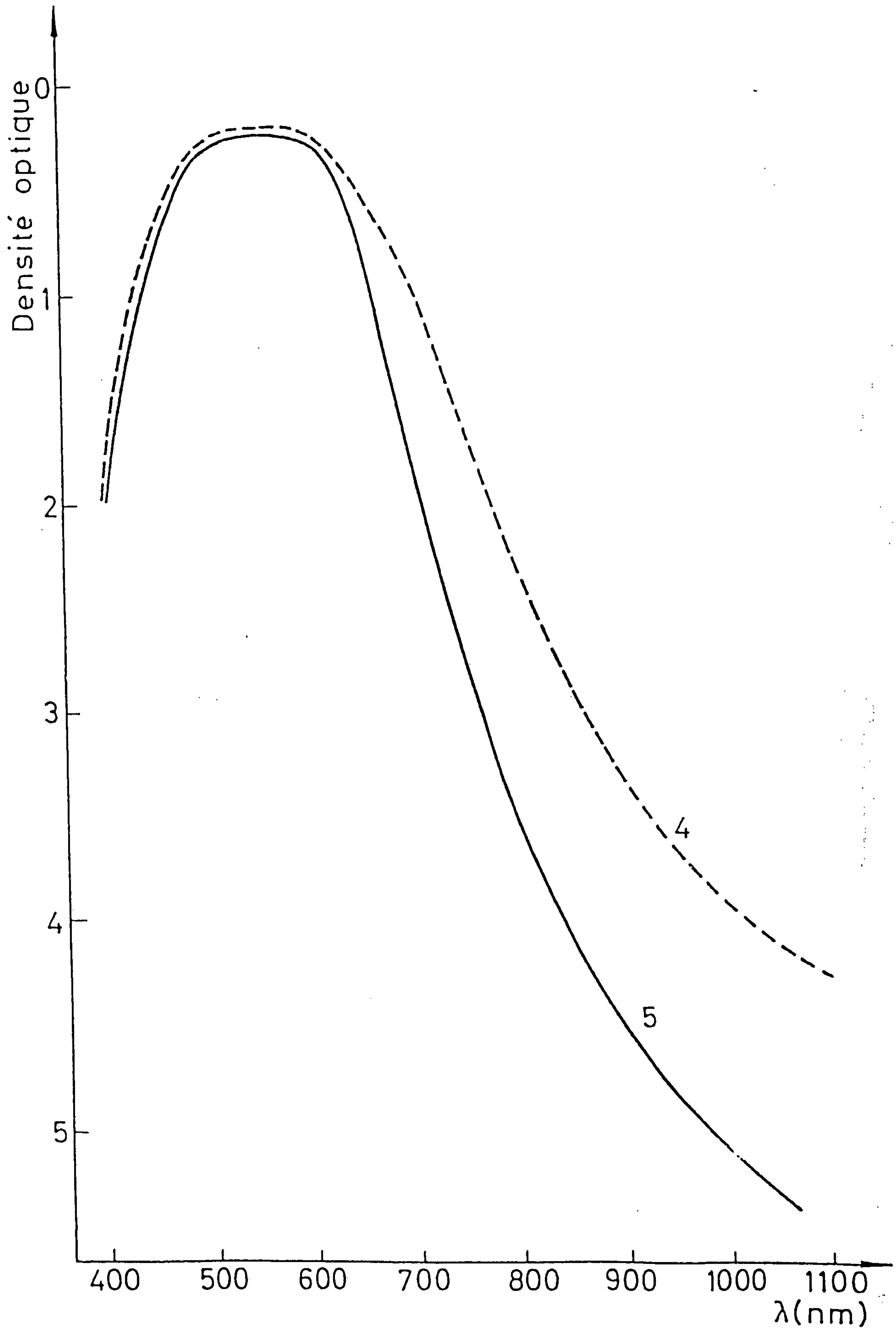

Densité optique
0
1
2
3
4
400
500
600
700
800
900
1000
1100
λ(nm)
1
2
3

FIG. 3



Densité optique
0
1
2
3
4
5
4
5
400
500
600
700
800
900
1000
1100
λ(nm)

FIG. 4

Reference AL-1

EXHIBIT
REFERENCE
AL-1

A TRANSLATION

AD-EX® WORLDWIDE

TRANSLATORS FOR INDUSTRY SINCE 1957

From FRENCH

Filtre optique interférentiel de protection contre les radiations infrarouges et application.

Into ENGLISH

OPTICAL INTERFERENCE FILTER FOR PROTECTION AGAINST INFRARED RADIATION AND APPLICATION

Author/s/ of original text:

GUY FARGES (INVENTOR)

Source of original text:

EUROPEAN PATENT APPLICATION NO. 0031278A1

Translated for:

IRELL AND MANELLA
MENLO PARK, CA

Per client order:

COPY

AD-EX Job No. 86148 Date 9 JULY 1990

AD-EX TRANSLATIONS INTERNATIONAL/USA
Tel. (415) 854-6732 or (800) 223-7753 ◆ FAX (415) 325-8428 and (415) 325-7409 ◆ Telex 17-1425 AD EX USA MNPK
525 Middlefield Road — Suite 150, Menlo Park, California 94025, U.S.A.